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Streamwise Development of the Flow over a Delta Wing

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Nomenclature

b = wing span
C_0 = wing root chord
K_p = constant of proportionality in potential flow lift equation
R = effective radius of integration grid
S = local semi-span
V = freestream velocity

Abstract

AN experimental investigation of the low-speed flow over a highly swept delta wing with sharp leading edges and at high angle of attack is presented. Velocity measurements in the separated leading-edge vortex are shown for several different chordwise stations, and serve to illustrate the streamwise development of the vortex. From these measurements the total vortex circulation has been calculated and is shown to compare well to that obtained theoretically by Polhamus. It is found that the vortex flowfield does not exhibit axisymmetry nor does it scale linearly with the half-span; a contradiction of two widely used assumptions in previous theoretical analyses. In the region of the axis of rotation, the viscous character of the flow becomes important and the core is found to grow linearly with downstream distance, while the maximum velocity is found to decrease with downstream distance.

Contents

With the advent of the Concorde SST and new classes of fighters such as the F-16 and the F-14, interest has grown in the flowfield about their highly swept wings, particularly at high angles of attack. The predominant characteristic of the flowfield over such wings is the production of leading-edge vortices. In order to study the structure and effects of this three-dimensional vortex flow, many painstaking measurements are required. Wentz and McMahon,[1] Hummel,[2] and Earnshaw[3] have made some measurements in this area. More recently, Sforza et al.[4] have made such measurements on several delta models, which include effects of sweepback, angle of attack, and longitudinal and transverse camber. Another recent detailed investigation of leading-edge vortex flows has been reported by Verhaagen and Van der Snoek.[5]

The present investigation is limited to the determination of the three-dimensional velocity field above the surface of a 75 deg sweepback delta with sharp leading edges and at a high angle of attack (29 deg). Measurements in planes normal to the planform at the 50, 65, 80, 95, and 110% chord stations have been taken in order to determine the streamwise development of such flows. This study of the vortex flowfield was performed in the wind tunnel described in Ref. 4. A special traversing mechanism with five degrees of freedom was used in conjunction with a three-dimensional directional (Conrad-type) probe 0.32 cm in diameter to obtain the velocity vector. In this investigation, a single delta wing test model 0.635-cm thick with 75-deg sweepback, 30-deg chamfered leading edges, 30.5-cm span, and an aspect ratio of 1.07 was employed. Extensive smoke flow visualization studies with and without the probe in the vortex showed no changes in vortex integrity. Natural bursting occurred, in either case, well downstream of the trailing edge. Data were taken in planes normal to the delta at a nominal freestream velocity of 4.06 m/s and a nominal Reynolds number, based upon the chord, of 1.5×10^5. The coordinate system utilized has X aligned with the centerline chord, Y normal to the surface, and Z in the spanwise direction. Nondimensional contours of constant velocity magnitude for the various measurement stations are presented in the full paper. The contours were used to generate the trajectory of the vortex core. This agreed very well with the trajectory determined by Elle,[6] who utilized smoke photographs of a 76-deg sweepback delta at the same angle of attack.

Profiles of the normalized vertical and spanwise velocity components V_Y/V and V_Z/V are presented in Figs. 1 and 2. Figure 1 shows V_Y/V as a function of spanwise coordinate (Z/S) at the core height. It can be seen that the maximum velocity ratio (V_Y/V) for each measurement station occurs roughly at the same nondimensional spanwise location. The spanwise component of velocity, V_Z/V, is presented in Fig. 2 as a function of distance above the surface. Here substantial differences are found to exist between the maximum values of the spanwise velocity components below the core for the several measurement stations. Note that in Fig. 2 the position of the core for the 1.10 C_0 station is shifted up in Y/S due to the upward bending of the vortex relative to the delta surface caused by the flow passing the trailing edge of the delta. From the V_Y/V and V_Z/V plots an asymmetry is observed as the vortex core position is crossed. This result is even more apparent on the plots of constant velocity contours. A vortex core diameter can be inferred from the preceding velocity profiles. Here the diameter of the core is assumed to be equivalent to the distance between the peak speeds that appear on the V_Z/V velocity profile in Fig. 2. The core diameter δ, determined in this fashion, grows linearly to the trailing edge $(\delta \simeq 0.1x)$.

The experimental results can be directly integrated to determine the circulation of the vortex. This is accomplished by employing a square grid with the vortex core at the center and using the circulation equation in the form

$$\Gamma = \iint (V_Y \mathrm{d}y + V_Z \mathrm{d}z)$$

An effective radius R is defined by taking the area of a given square in the grid, equating it to the area of a circle, and finding the resulting radius for that area. A plot of the variation of the circulation with effective radius from the vortex core for the several measurement stations is shown in Fig. 3. Polhamus[7] has shown that the circulation for a delta

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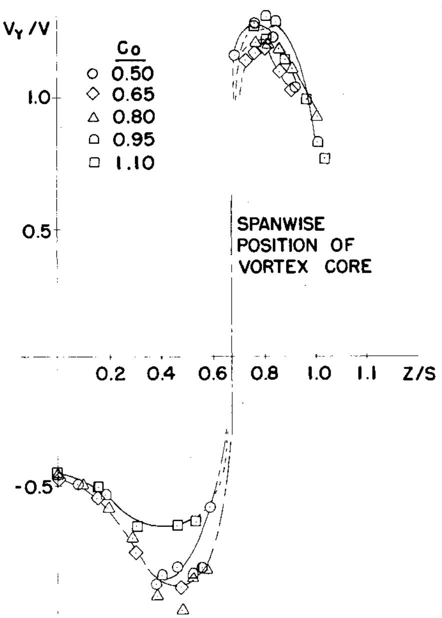

Fig. 1 Spanwise variation of velocity component V_Y/V through vortex core.

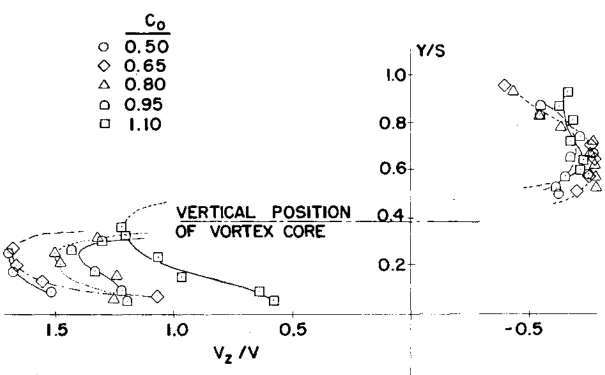

Fig. 2 Vertical variation of velocity component V_Z/V through vortex core.

of area A is given by

$$\Gamma = K_P \frac{A}{2} \frac{V}{b} \sin\alpha$$

For the test delta, the circulation calculated in this manner appears to be an asymptote to the experimentally derived

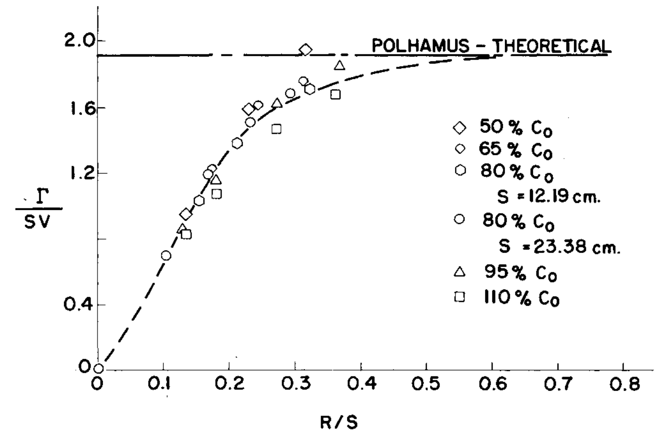

Fig. 3 Normalized circulation distribution for various streamwise locations.

circulation, as can be seen in Fig. 3. Circulation calculations were also made for a previously tested larger model, but only at the 80% chord location. These data are identified in Fig. 3 by the larger semispan value. It appears that significant weakening of the vortex only starts at 110% C_0, or beyond the trailing edge of the delta. The other data followed the faired curve quite closely, except for one of the 50% C_0 points. The significance of that departure from the remaining data is not clear at the present time.

References

[1] Wentz, W. H. and McMahon, M. C., "An Experimental Investigation of the Flow Fields about Delta and Double Delta Wings at Low Speeds," NASA CR521, 1966.

[2] Hummel, D., "Untersuchungen uber das aufplatzen der wirbel au schlanken delta flugeln," *Zeitschrift fur Flugwissenshaft*, Vol. 13, Heft. 5, 1965, pp. 158-168.

[3] Earnshaw, P. B., "An Experimental Investigation of the Structure of a Leading-Edge Vortex," Aeronautical Research Council R&M No. 3281, March 1961.

[4] Sforza, P. M., Stasi, W., Pazienza, J., and Smorto, M., "Flow Measurements in Leading Edge Vortices," *AIAA Journal*, Vol. 16, March 1978, pp. 218-224.

[5] Verhaagen, N. G. and Van der Snoek, L., "An Experimental Investigation of the Entrainment of a Leading Edge Vortex," in *High Angle of Attack Aerodynamics*, AGARD-CP-247, 1979.

[6] Elle, B. J., "An Investigation at Low Speed of the Flow Near the Apex of Thin Delta Wings with Sharp Leading Edges," Aeronautical Research Council R&M No. 3176, Jan. 1958.

[7] Polhamus, E. C., "A Concept of the Vortex Lift of Sharp-Edge Delta Wings Based on a Leading Edge Suction Analogy," NASA TN D3767, 1966.